The continuing demand for more performance, complexity and cost reduction require the semiconductor industry to develop microcontrollers with both high density design technology and higher clock frequencies. This has intrinsically increased the noise emission and noise sensitivity. The microcontrollers are affected by transient events like electrostatic discharge. The effect of the Human Body Model of electrostatic discharge to the MC9S08QE128-8 bit microcontroller circuit is analysed. The hardware circuitry has been configured to act like a diagnostic tool, indicating an error if the hardware fails. Direct air discharge has been conducted on the connector GPIO pins in the neighbourhood of the active I/O pins. The results show that the impedance of the board becomes very low implying there is a dead short between the VDD and the VSS rails.

**Keywords:** Electrostatic discharge, Human body model, Microcontroller, Air discharge, Electromagnetic interference

**INTRODUCTION**

When it comes to protecting the designs from a variety of transient electrical disturbances, microcontroller-based embedded systems in consumer, industrial, and automotive electronics are faced with two dilemmas. On one hand, more sophisticated and noise-sensitive microcontrollers (MCUs), with high integration, tighter process requirements and lower voltage requirements are moving into designs that are increasingly hazardous with respect to electromagnetic interference (EMI) and electrostatic discharge (ESD). On the other, increased competition, as well as market regulatory pressures, are forcing Original Equipment Manufacturers (OEMs) to reduce the cost of their products. As a result of this focus on cost control, implementing the necessary transient immunity protections to prevent application malfunction due to
transients on power and signal lines is becoming ever more challenging.

Low-cost microcontroller-based embedded applications are particularly susceptible to performance degradation during ESD and Electrical Fast Transients (EFT) events (Ross Carlton et al., xxxx; IEC 61000-4-2, 2001; and IEC 61000-4-4, 2001). This sensitivity to fast rise time transients is to be expected, even for microcontrollers running at relatively low clock frequencies. This sensitivity is due to the process technologies employed. Today’s semiconductor process technologies for low-cost, 8-bit and 16-bit microcontroller units (MCUs) implement transistor gate lengths in the 0.65µm to 0.25 µm range. These gate lengths are capable of generating and responding to signals with rise times in the sub-nanosecond range (or an equivalent bandwidth of greater than 300 MHz).

Integrated Circuits (ICs) based on submicron process technologies are capable of responding to fast transients injected onto its pins. Controlling ESD/EFT events at the IC level is particularly important for microcontrollers, since these ICs are used in very cost sensitive safety-critical applications, where it may not be practical to solve ESD/EFT problems at the board level and where IC failure can have much more significant consequences than simply needing to reboot your computer.

A MCU is quite capable of responding to ESD or EFT signals injected onto its pins. Several facets of IC design other than physical gate length can affect MCU performance during transients. These include the composition of ESD suppression devices on input/output (I/O) pins and the layout of I/O pin structures. In addition to the process technology, MCU performance in the presence of an ESD or EFT event is affected by the design of the IC and its package, the design of the Printed Circuit Board (PCB), the software running on the MCU, the design of the system, and the characteristics of the ESD or EFT waveform when it reaches the MCU (Bernard, 1987; Ronald, 1989; Ronald, 1989; Clayton, 1992; Larry, 1994; Ken, 2004; and Lun, xxxx).

In order to quantify the effect of ESD on the 8-bit microcontroller (Carlton et al., xxxx; Lamoureux et al., 2005; Dhia et al., 2006; and Beetner et al., 2007), MC9S08QE128 microcontroller is used. The hardware circuitry has been configured to act like a diagnostic tool, indicating an error if the hardware fails. Direct air discharge has been conducted at 4 kV, 8 kV and 12 kV to the connector GPIO pins in the neighbourhood of the active I/O pins.

**CIRCUIT AND OPERATION**

The hardware circuitry is designed to exercise most of the hardware in the microcontroller simulating a diagnostic tool, indicating an error if the hardware fails. To accomplish this task, on chip peripherals like digital ports, UART, PWM channels, timers are used. The schematics are as shown in the Figure 1. The circuit components are

- MC9S08QE128 8bit Microcontroller
- LEDs
- LD33 – low drop out regulator
- Power Pack (5-6 V)

A 3 terminal voltage regulator is used to supply 3.3 V to the entire circuit. The
Microcontroller has an internal clock source of 1 kHz and using an internal phase locked loop (PLL), the frequency is pumped up to 4 MHz (bus clock).

Three tests have been designed to achieve this and they are as follows.

**Test 1**: Involves Digital ports, Port D and Port E.

**Test 2**: Involves UART1.

**Test 3**: Involves PWM channels TPM3CH1 and TPM3CH2 run from Timer 3.

A LED is connected to a port, which is turned ON initially indicating no error condition at the start of the diagnostic check. The LED continues to glow if all the tests pass. Failure of any test is indicated by the LED in OFF condition.

**TEST DESCRIPTION**

**Test 1**
Digital ports, Port-D and Port-E are configured as output and input ports respectively, connection details are given below.

PTD2 connected to PTE2.
PTD1 connected to PTE1.
PTD0 connected to PTE0.

Data of different bit patterns is written to the port-D data register and is read from the port-E data register, the data read from the input port is compared with the data written to the output port and if not equal then an error condition is raised.

**Test 2**
The UART is configured at 9600 baud, transmit and receive pins are externally connected in Figure 1: Schematic of the Microcontroller Circuit
loop back mode, a character is written to transmit buffer and data is received in the receive buffer. If received data is not equal to the transmitted data an error condition is raised.

**Test 3**

Timer 3 is configured at 100 ms. Two PWM channels are connected to the LEDs D2 and D3. The duty cycle is varied in steps to change the intensity of the light and is driven out of phase.

**SYMPTOMS INDICATING FAILURE**

- Status LED D4 does not glow.
- PWM LEDs D2 and D3 do not ramp up or down.

After a failure, followed by a power cycle if the circuit does not work normally, it indicates permanent damage.

For MCUs, performance degradation can take many forms. Common forms of temporary degradation include but are not limited to reset, latch-up, memory corruption, and code runaway. MCUs with internal reset circuits can generally resume operation without operator involvement if the fault is an unexpected reset or code runaway that is caught by a watchdog timer.

Recovery from latch-up and volatile memory (RAM, DRAM, etc.), corruption requires cycling the power to the system. Non-volatile memory (FLASH, EEPROM, ROM, etc.), corruption requires a more extensive process of re-programming the system, which can be viewed as a temporary MCU degradation if the system can be re-worked, or as a permanent degradation if it cannot be re-worked.

Permanent degradation can include increased leakage current on I/O pins which can affect analog measurements, input impedances, and output drive strength. With increased leakage current, the electronic system may still operate within specification for a while, but it may ultimately fail due to damage from the transient stress. Another type of permanent degradation found in transient environments is blown pins due to an electrical overstress.

**OBSERVATIONS AND RESULTS**

A single shot direct air discharge at 4 kV, 8 kV and 12 kV to the connector GPIO pins in the neighbourhood of the active I/O pins caused the LEDs D2 and D3 to switch off and its functionality was restored by power on reset. When the discharge from the ESD gun was pulsed more than once at 12 kV, all the LEDs stopped functioning and the microcontroller was not restored by power on reset. The batteries and the microcontroller also got heated up.

The analysis of the effect of ESD is done by isolating the voltage regulator, the capacitor, the diode and the microcontroller one by one from the board. The VDD (Pin 4) and the VSS (Pin 9) lines are dead short and drew heavy current causing the microcontroller to heat up. Hence the microcontroller shut down on its own due to thermal shut down.

The board impedance which is typically 1 KΩ is reduced to 4.4 Ω as shown in Figure 2 because of a punch through in the GPIO pin. The board impedance remains 4.4 Ω in the 3.3 V rail even after isolating the capacitor, diode and the voltage regulator; therefore
these components are not affected by ESD. The board impedance goes out of range once the microcontroller is isolated from the board as shown in Figure 3. The pull up circuitry driving the LEDs D2 and D3 connected to the PWM channels is damaged due to ESD. It does not turn on even with a direct supply of 5 V and hence the diodes D2, D3 are burnt.

**Post Effects**

The LED D4 is in the working condition with reduced intensity when it is directly powered up and the Microcontroller is still on the board as shown in Figure 4. The LED D4 glows with full intensity when the Microcontroller is isolated from the board and direct 5 V is applied across the terminals as shown in Figure 5.

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**Figure 2: Board Impedance of 4.4Ω**

![Image of a board impedance meter showing 4.4Ω](image2.jpg)

**Figure 3: Board Impedance Goes Out of Range When the Microcontroller is Isolated**

![Image of a board impedance meter with impedance out of range](image3.jpg)

**Figure 4: LED D4 with Reduced Intensity**

![Image of LED D4 with reduced intensity](image4.jpg)

**Figure 5: LED D4 When 5 V is Connected Across it**

![Image of LED D4 illuminated with 5 V supply](image5.jpg)
CONCLUSION

The direct air discharge of 12 kV on a GPIO pin with close proximity to the active I/O pins leads to the shorting of power rails VDD and VSS which resulted in thermal shut down of the microcontroller. The pull up circuitry driving the LEDs D2 and D3 connected to the PWM channels are damaged irrevocably. The diode D4 did not glow when the circuit is powered after the ESD test up indicating failure of all three tests.

REFERENCES


